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Flexible and Highly Scalable Concept for an FMCW LiDAR PIC based on Slanted Grating Couplers

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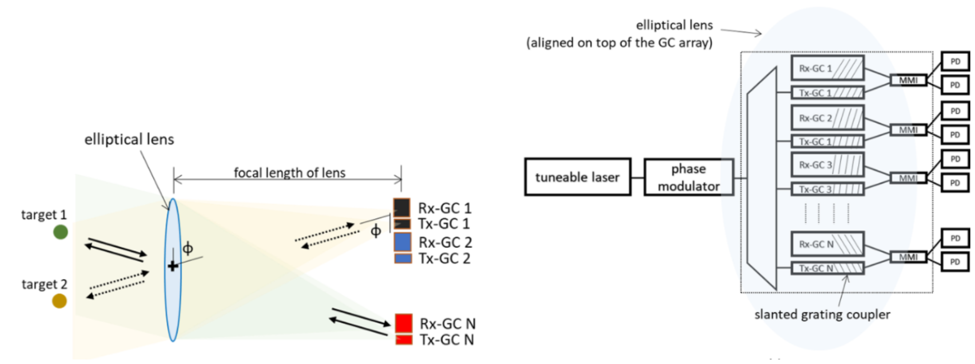
Abstract: We propose a novel FMCW LiDAR Photonic Integrated Circuit that relies on slanted grating couplers. Our simulations on an SOI waveguide structure show that the concept is feasible with a FOV of 100° by 12°.

1. Introduction

Photonic integration is the only technology able to provide compact, low-power, and affordable Frequency-Modulated-Continuous-Wave (FMCW) LiDAR systems [1, 2]. Conventional photonic-integrated FMCW LiDAR concepts typically rely on the optical phase arrays (OPAs) to generate and scan a pointed beam across the field-of-view (FOV) [3]. One of the major limitations of this concept is that it requires many individually-controlled phase shifters and an elaborate calibration of all the individual elements to achieve full 2D beam steering. In addition, scanning a scenario point-by-point results in a relatively slow capture of the whole FOV, due to the round-trip time from the transmitter to the target before moving to the next point in the medium of propagation. The proposed architecture is based on pure passive structures, as it does not require OPAs or a large number of individually-controlled phase shifters to accomplish 3D environmental mapping. Furthermore, we simultaneously illuminate and measure the light received from all angular directions to reduce the capture time of the point cloud. This work describes our concept for a FMCW LiDAR and presents results for the design of the slanted Grating Couplers(GCs).



(a) Illustration of the FMCW LiDAR PIC based on slanted grating couplers

(b) schematic overview of the whole PIC showing the linear array of grating couplers, PD=photodiode.

Fig. 1

2. FMCW LiDAR PIC based on Slanted Grating Couplers

Figure 1a illustrates the concept of our proposed FMCW LiDAR PIC based on slanted grating couplers. The concept relies on transmitting multiple beams towards all directions through a transmitter grating coupler (Tx-GC) and receiving the signal reflected from a target using a receiver (Rx) GC located directly next to the Tx-GC. An elliptical lens is used to collimate the beam from the Tx-GC to achieve a very small diffraction angle. Similarly, an incoming signal from the same direction will focus on the Rx-GC situated directly next to the Tx-GC. Figure 1b shows a schematic of the complete FMCW LiDAR PIC. Light from a fast-tunable laser is passed through a phase modulator, and then divided by a star coupler among all the Tx-GCs. Each Tx-GC then radiates the light out of the PIC toward one specific direction, after collimation by the elliptical lens. After reflection from a target, the light is reflected towards the same direction and therefore collimated by the lens on almost the same location as the Tx-GC. In order to have a minimal deviation between the Tx-GC- and Rx-GC acceptance angle, we have designed the Tx-GC waveguide to be narrower than that of the Rx-GC. After the Rx-GC, the incoming signal is mixed with a portion of the signal that was left over after the Tx-GC in a 2x2 multi-mode interference (MMI) coupler and guided towards the balanced detector. Note that this concept allows for FMCW coherent detection for all Tx-Rx directions simultaneously, leading to reduction in signal processing time, as opposed to point-by-point LiDAR PICs that radiate a pointed beam in only one direction. Our proposed architecture offers many advantages over existing LiDAR PICs. The most notable advantage being that it does not rely on optical phased arrays that typically require a large amount of phase shifters with an elaborate calibration procedure to control the laser beam. In addition, the scalability of the architecture towards a large number of channels for increased angular resolution is relatively straightforward. Another notable advantage is the flexibility due to the fact that the tunable laser, phase modulator, and photodiodes (PDs) do not necessarily have to be integrated on the same PIC as the Tx-GC- and Rx-GCs arrays (see dashed line on figure 1b) for the system to work. Therefore, the passive Tx-GC- and Rx-GCs arrays can be integrated on virtually any material platform, since there are no fast phase modulators required (as in the case of OPAs [4]).

3. Slanted Grating Coupler Design

In order to test the feasibility of our architecture and calculate the field-of-view (FOV), we have simulated the slanted grating coupler performance for the SOI waveguide structure shown in figure 2a. Figure shows a top view of the slanted grating coupler illustrating how the slanting in the grating coupler was introduced. The waveguide width is 5µm. Figure 2c shows the far-field pattern of slanted GC for 5 different positive and negative slanting angles. This result shows that the radiation angle can be shifted up to ±50º by slanting the gratings up to ±16º before the radiated power starts dropping (see figure 2d). Figure 2e shows the steering of the radiation angle in the perpendicular direction (see figure 2a) which is controlled by the wavelength of the laser. This plot shows that the steering in this direction is limited to around 12º when changing the wavelength by 100nm. For this implementation in SOI technology only 30% is radiated upward, and therefore for future implementations more directional grating couplers are preferred such as the ones described in [5].

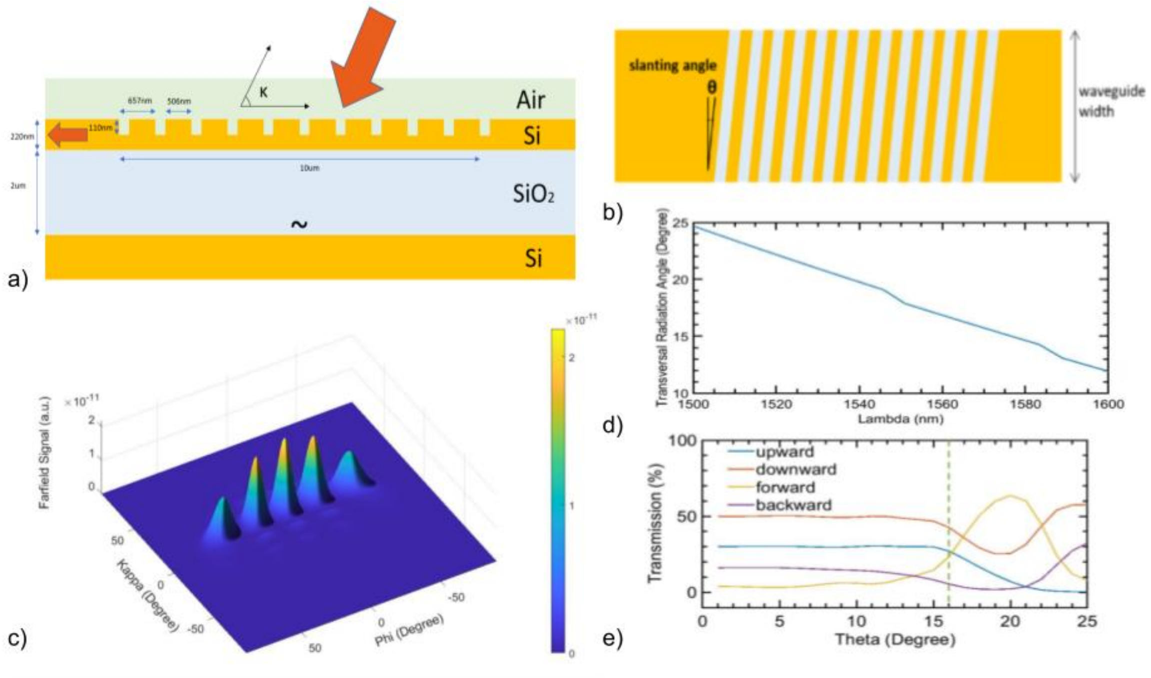


Fig. 2: **(a)** Illustration of the slanted GC waveguide structure; **(b)** top view of the slanted grating coupler; **(c)** simulated far-field radiation pattern for 5 different slanting angles; **(d)** simulated optical powers coupled out of the grating couplers in all direction; **(e)** simulated diffraction angle κ versus wavelength

The results demonstrate the viability of our FMCW LiDAR PIC. From the results shown above, we can calculate a FOV for our LiDAR PIC of 100º by 12º. The FOV in the longitudinal direction can be increased by adding angle-magnifying lenses on top of the PIC.

4. Conclusion

We have proposed and evaluated a concept for a FMCW LiDAR PIC, and show the feasibility of the concept based on simulations performed on slanted grating couplers. We have simulated a field-of-view of 100º by 12º. Our architecture offers many advantages over existing LiDAR architectures, such as highly scalable, flexibility of implementation on any waveguide platform since the laser and photodetectors can be placed off-chip.

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